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UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Medium Access – Carrier Sensing

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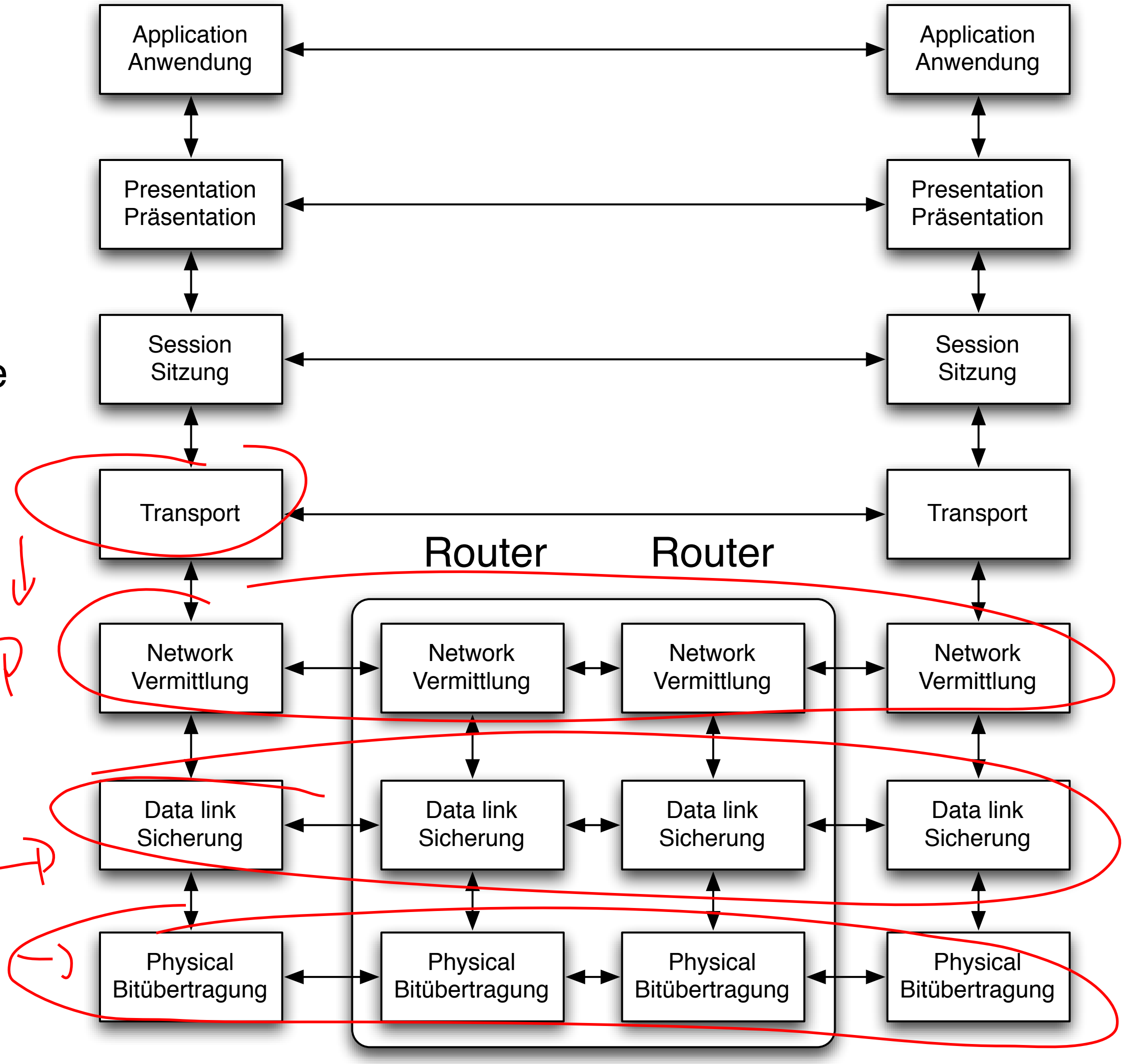
ISO/OSI Reference model

- **7. Application**
  - Data transmission, e-mail, terminal, remote login
- **6. Presentation**
  - System-dependent presentation of the data (EBCDIC / ASCII)
- **5. Session**
  - start, end, restart
- **4. Transport**
  - Segmentation, congestion
- **3. Network**
  - Routing
- **2. Data Link**
  - Checksums, flow control
- **1. Physical**
  - Mechanics, electrics

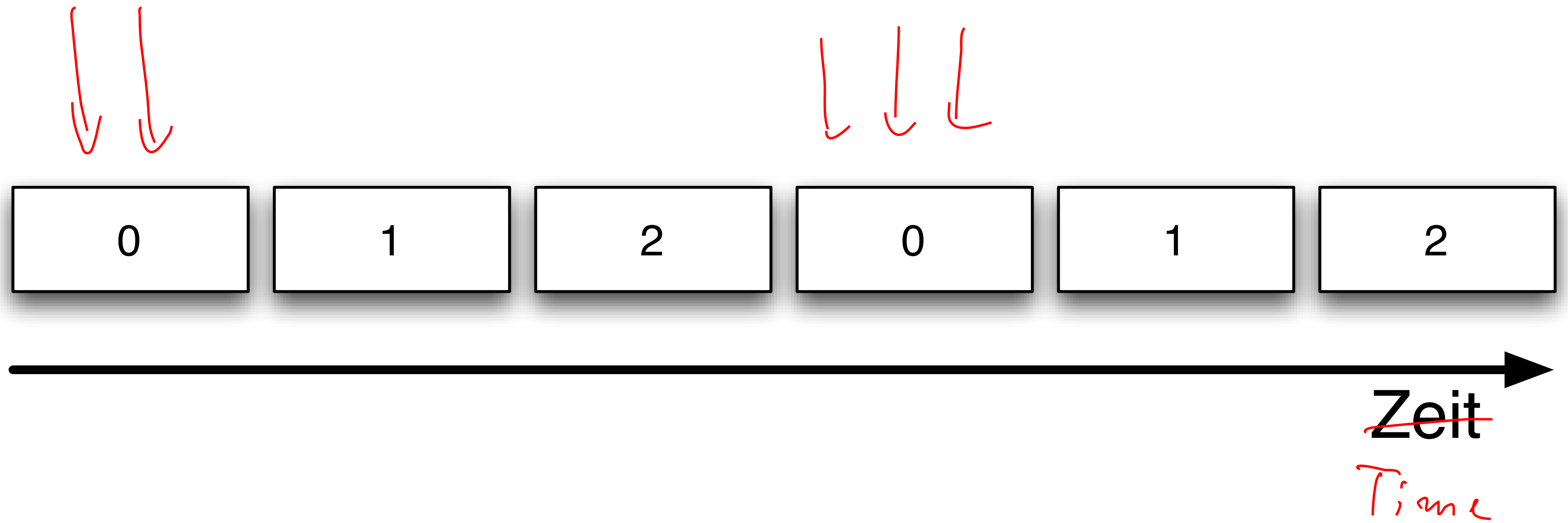


Types of Conflict Resolution

- **Conflict-free**
  - TDMA, Bitmap
  - FDMA, CDMA, Token Bus
- **Contention-based**
  - Pure contention Aloha
  - Resctricted contention
- **Other solutions**
  - z.B. MAC for directed antennae

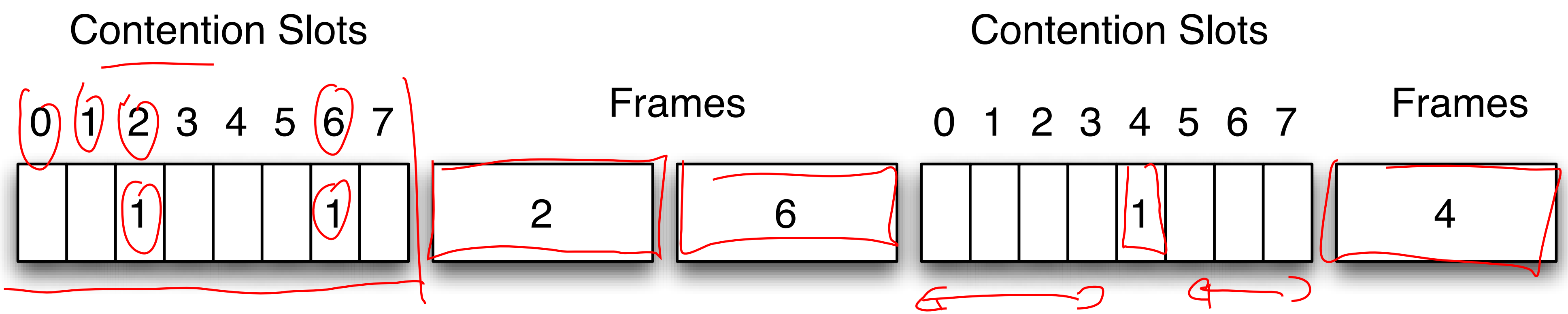
Contention Free Protocols

- **Simple Example: Static Time Division Multiple Access (TDMA)**
  - Each station is assigned a fixed time slot in a repeating time schedule
  - *Traffic-Bursts* cause waste of bandwidth



Bitmap Protokoll

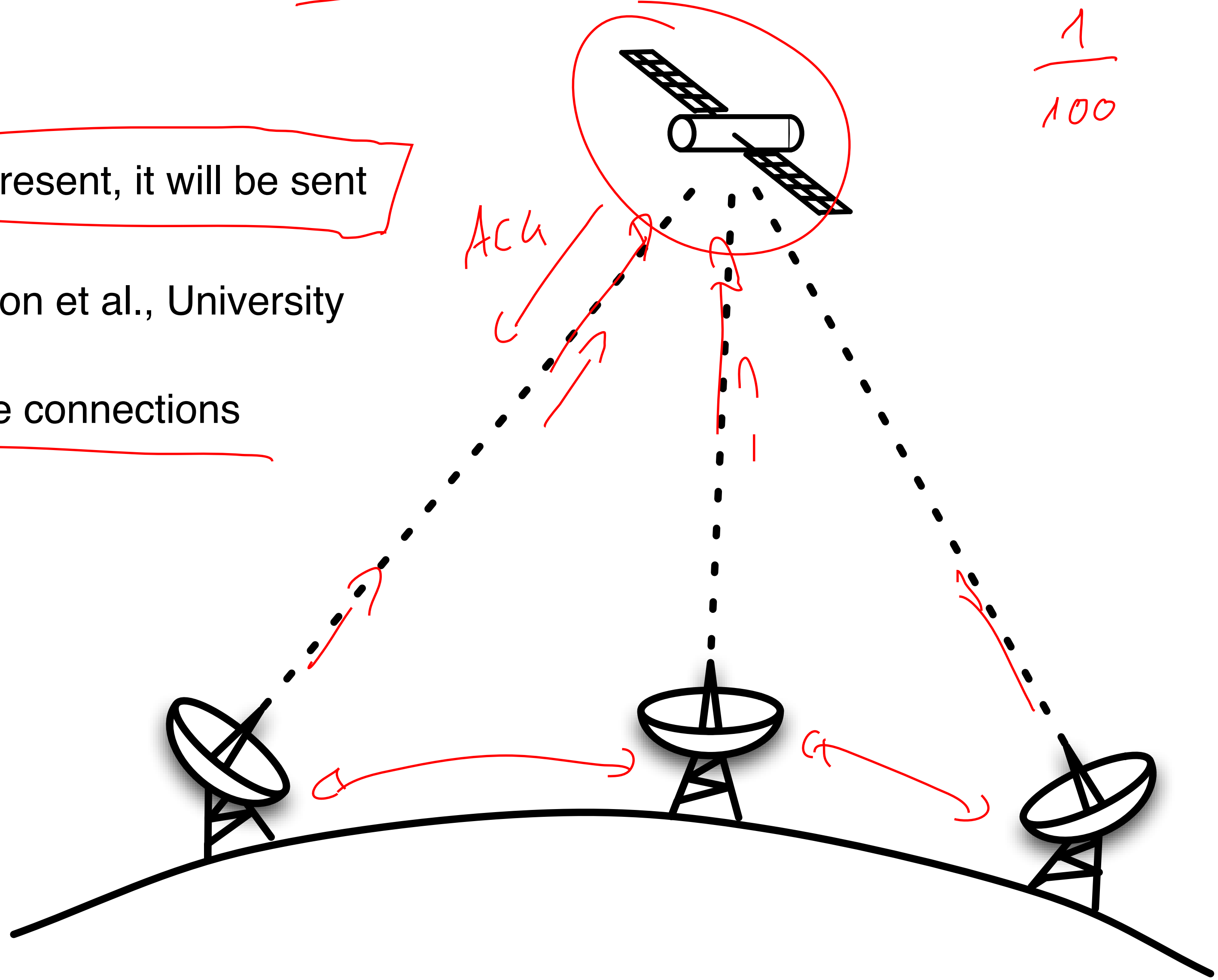
- **Problems of TDMA**
  - If a station has nothing to send, then the channel is not used
- **Reservation system: bitmap protoco**
  - Static short reservation slots for the announcement
  - Must be received by each station
- **Problem**
  - Set of participants must be fixed and known a-priori
  - because of the allocation of contention slots



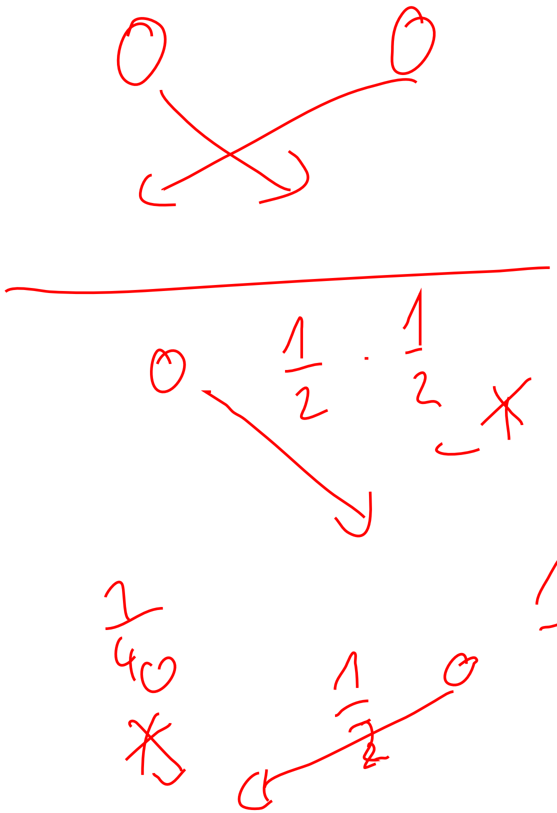
ALOHA

- **Algorithm**
  - Once a paket is present, it will be sent
- **Origin**
  - 1985 by Abrahmson et al., University of Hawaii
  - For use in satellite connections

$\frac{1}{100}$

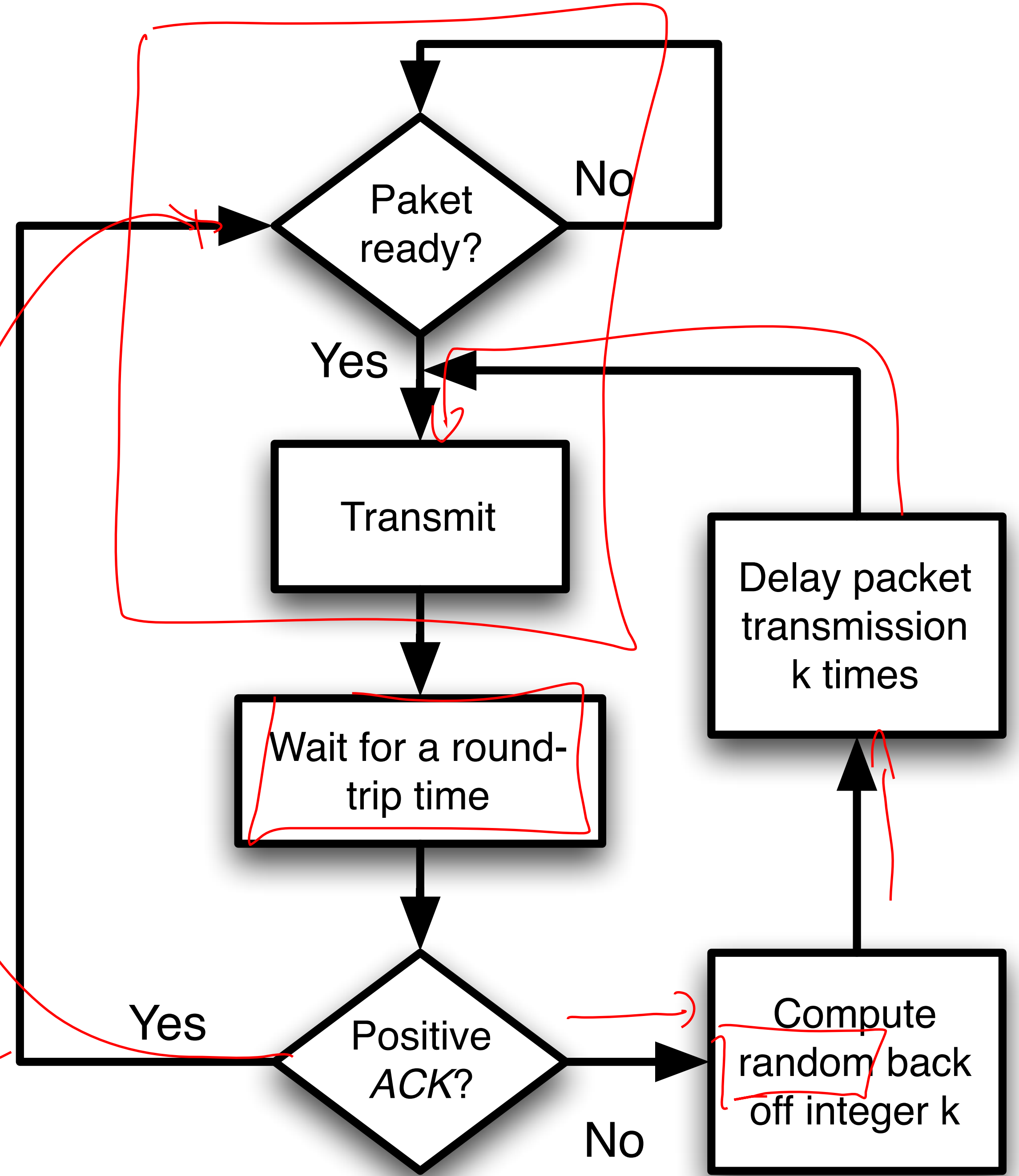


Aloha



$\frac{1}{2} \cdot \frac{1}{2}$

$\frac{1}{4}$ $\frac{1}{2}$ $\frac{1}{4} + \frac{1}{4} = \frac{1}{2}$



ALOHA – Analysis

- **Advantage**
  - simple
  - no coordination necessary
- **Disadvantage**
  - collisions
    - sender does not check the channel
  - sender does not know whether the transmission will be successful
    - ACKs are necessary
    - ACKs can also collide

$\sum_{k=2}^{\infty} \frac{1}{k!} \cdot e^{-1} = 1 - \frac{2}{e}$

ALOHA – Efficiency

$\frac{1}{0!} \cdot e^{-G} = \frac{1}{e}$

$k=0$

- **Consder Poisson-process for generation of packets**
  - describe “infinitely” many stations with similar behavior
  - time between two transmission is exponentially distributed
  - let G be the expectation of the transmission per packet length
  - all packets have equal length
  - Then we have $P[k \text{ transmissions}] = \frac{G^k}{k!} e^{-G}$

$G = \lambda$

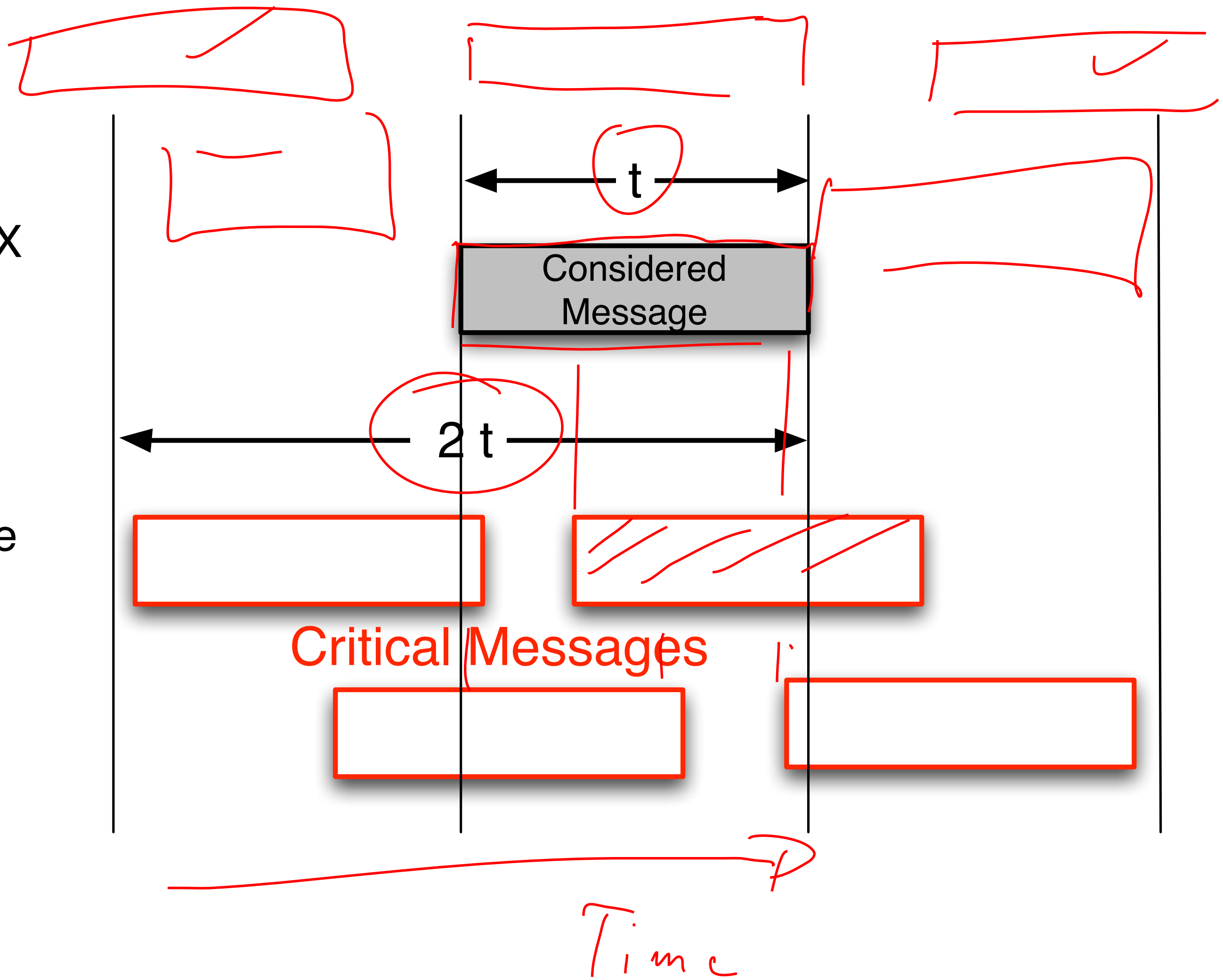
$G = 1;\ k = 1$

- **For a successful transmission, no collision with another packet may happen**
  - How probable is a successful transmission?

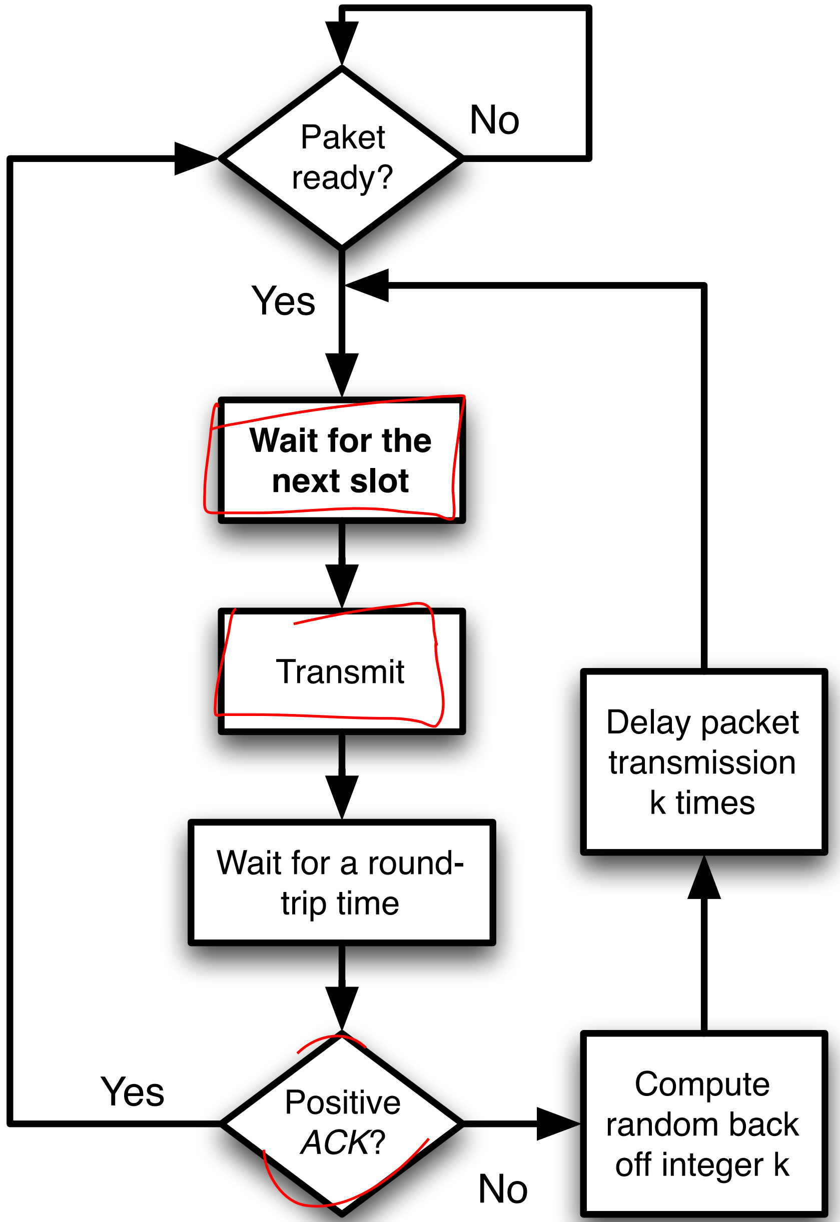
$\frac{1^{k}}{1} \cdot e^{-\cancel{G}1} = \frac{1}{e}$

ALOHA – Efficiency

- **A packet X is disturbed if**
  - a packet starts just before X
  - a packet starts shortly after X starts
- **A packet is successfully transmitted,**
  - if during an interval of two packets no other packets are transmitted



Slotted Aloha

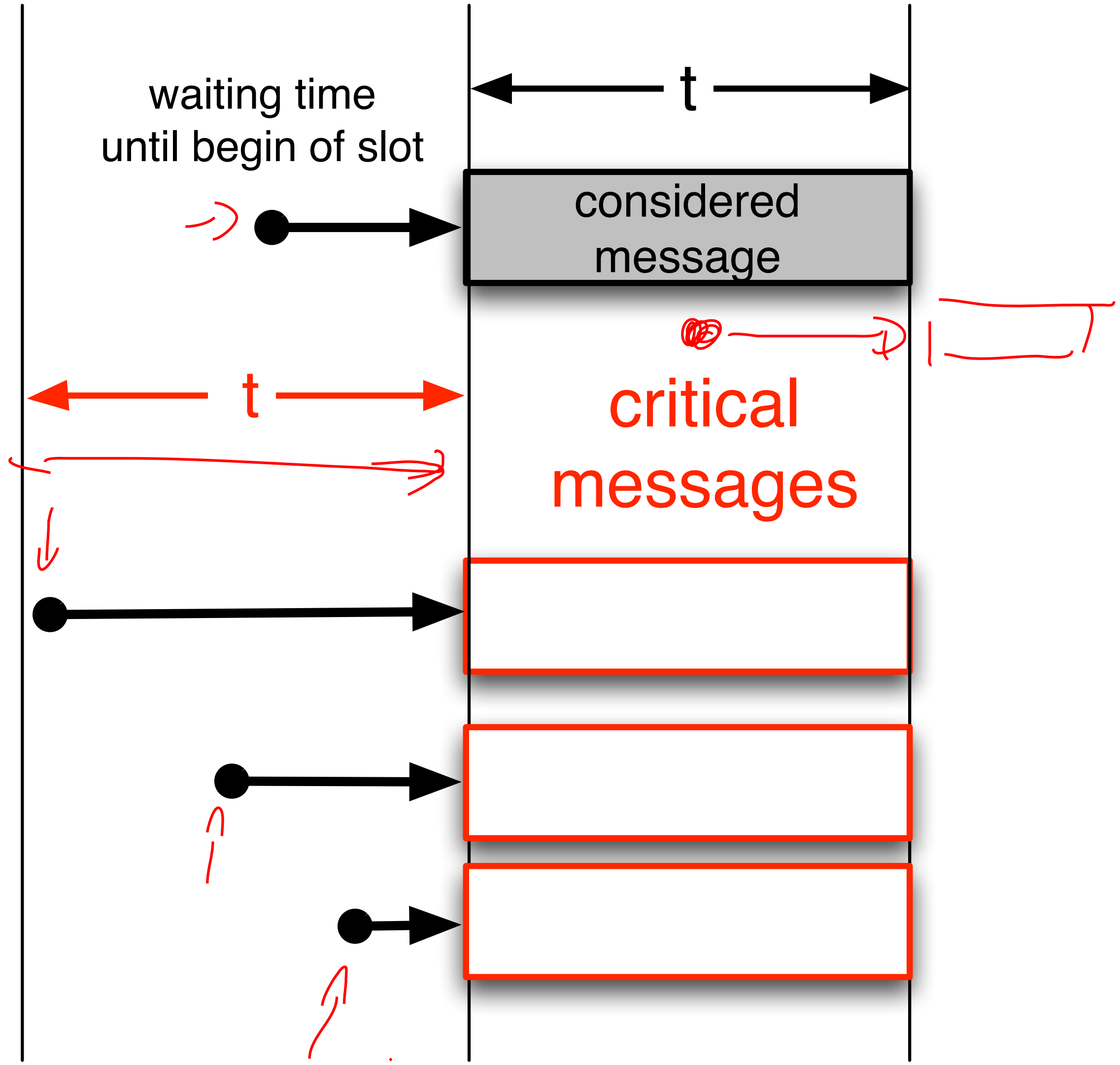


Slotted ALOHA

- **ALOHA's problem**
  - long vulnerability of a packet
- **Reduction through use slots**
  - synchronization is assumed
- **Result**
  - vulnerability is halved
  - throughput is doubled
    - $S(G) = Ge^{-G}$
    - optimal for G=1, S=1/e

Slotted ALOHA – Effizienz

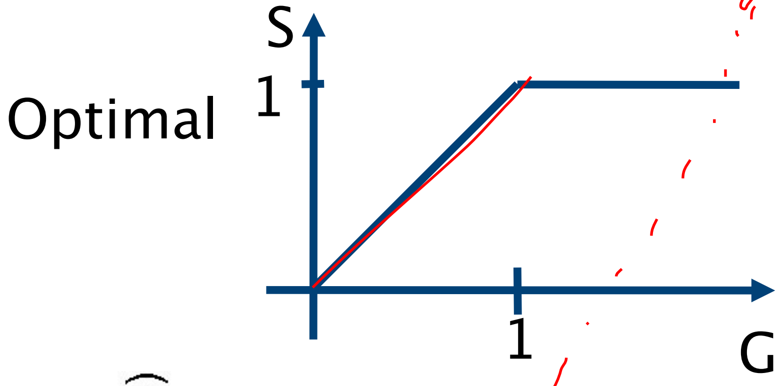
- **A packet X is disturbed if**
  - a package starts just before X
- **The packet is successfully transmitted,**
  - when transmitting over a period of **one** packets no (other) packets appears

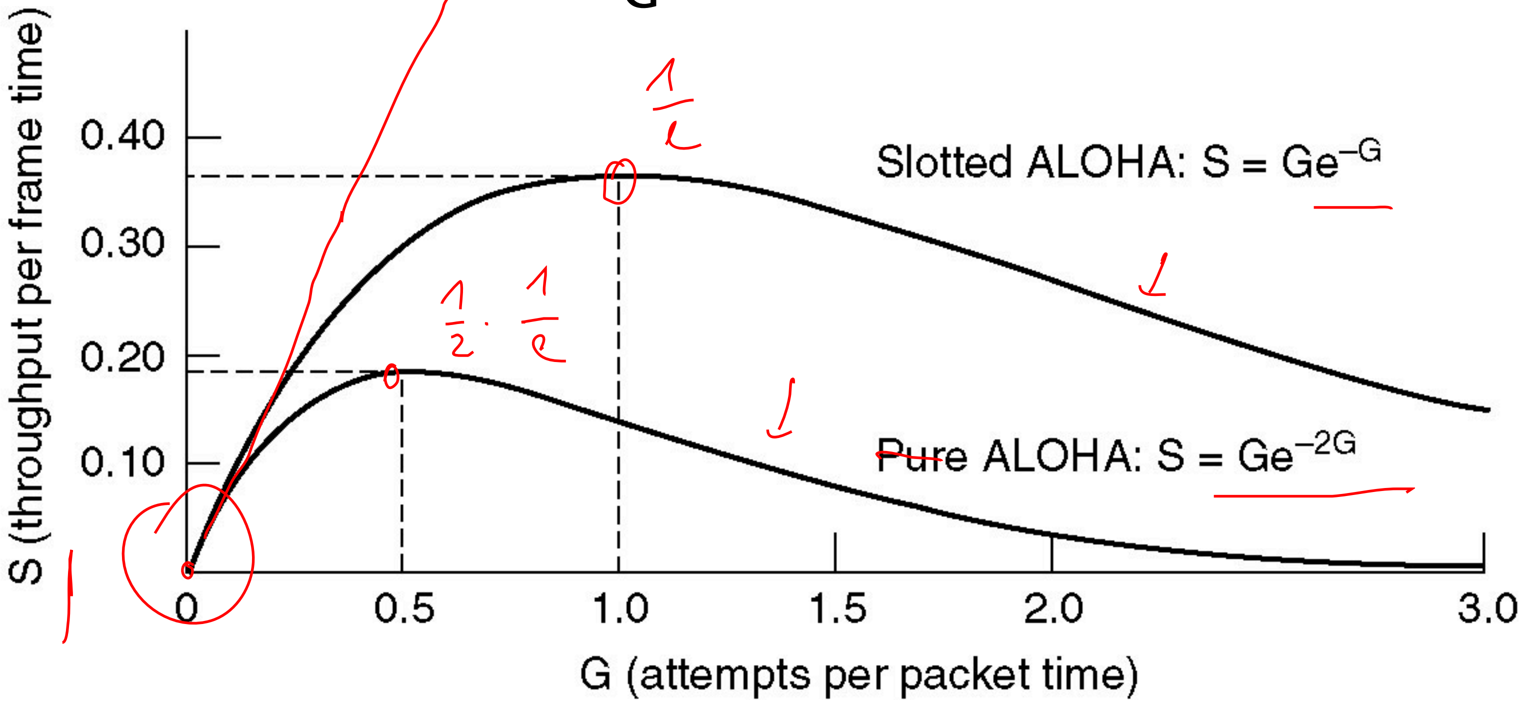


Throughput with respect to the Load

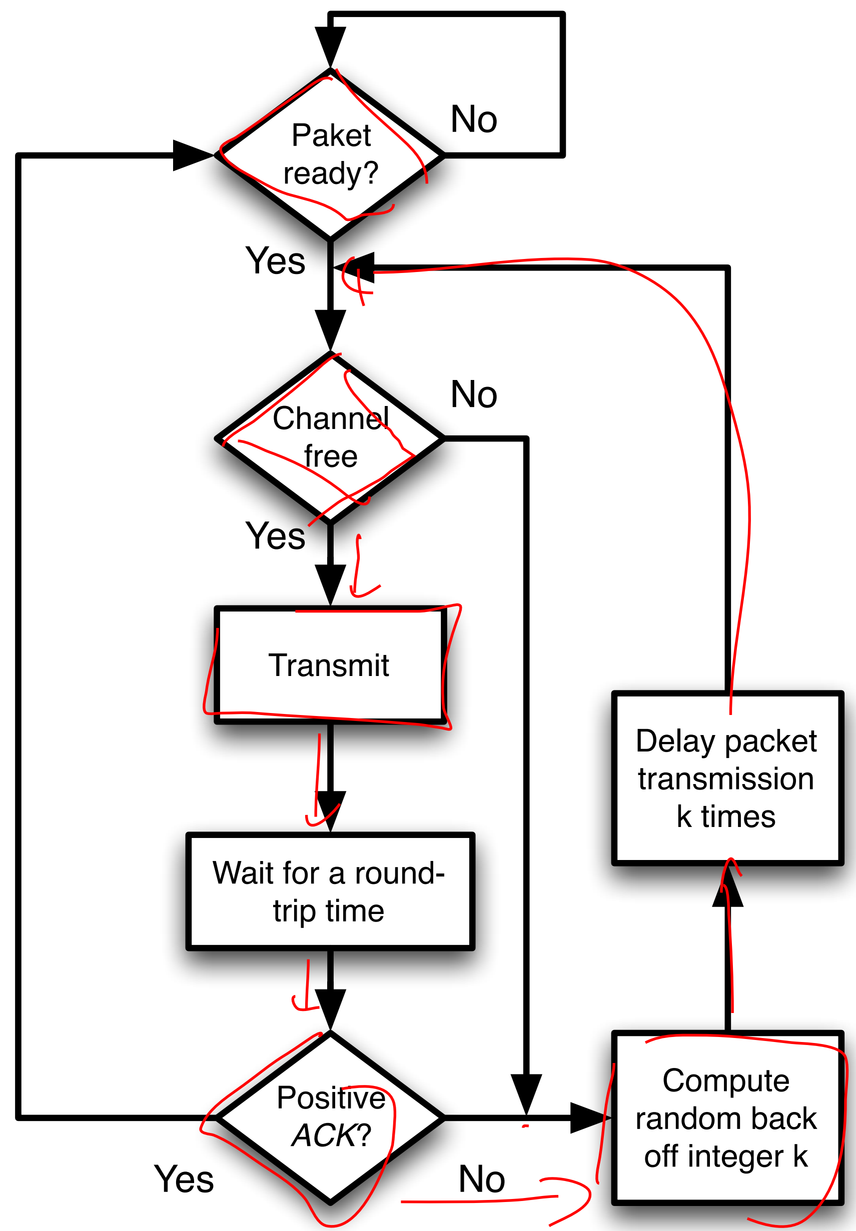
$G = 1$

100 players send w. prob. $\frac{1}{100}$



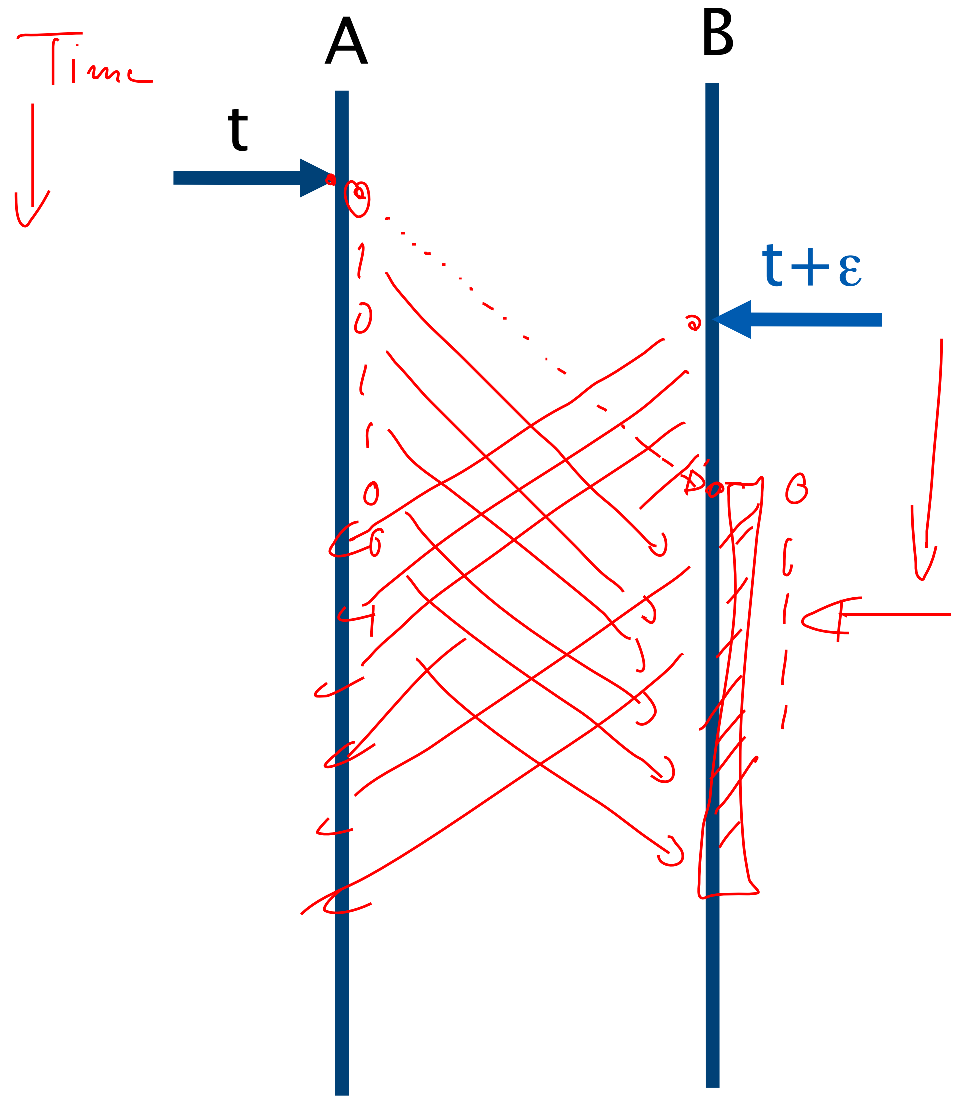


Carrier Sense Medium Access CSMA



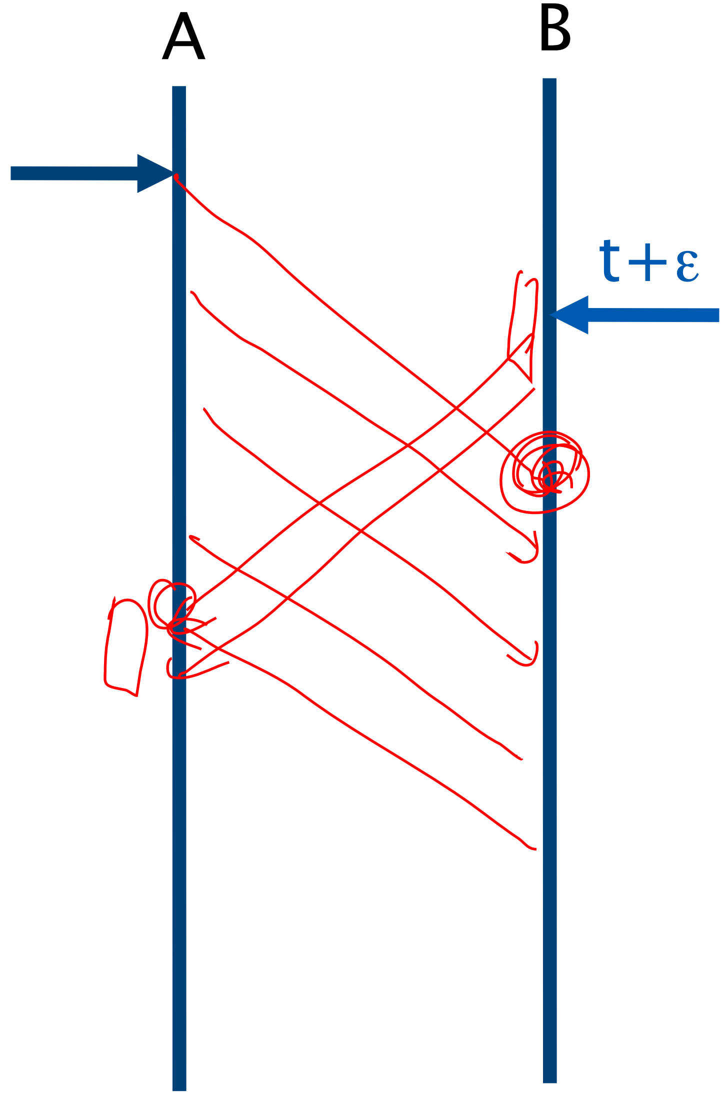
CSMA und Transmission Time

- **CSMA-Problem:**
  - Transmission delay d
- **Two stations**
  - start sending at times t and t + ε with ε <d
  - see a free channel
- **2nd Station**
  - causes a collision

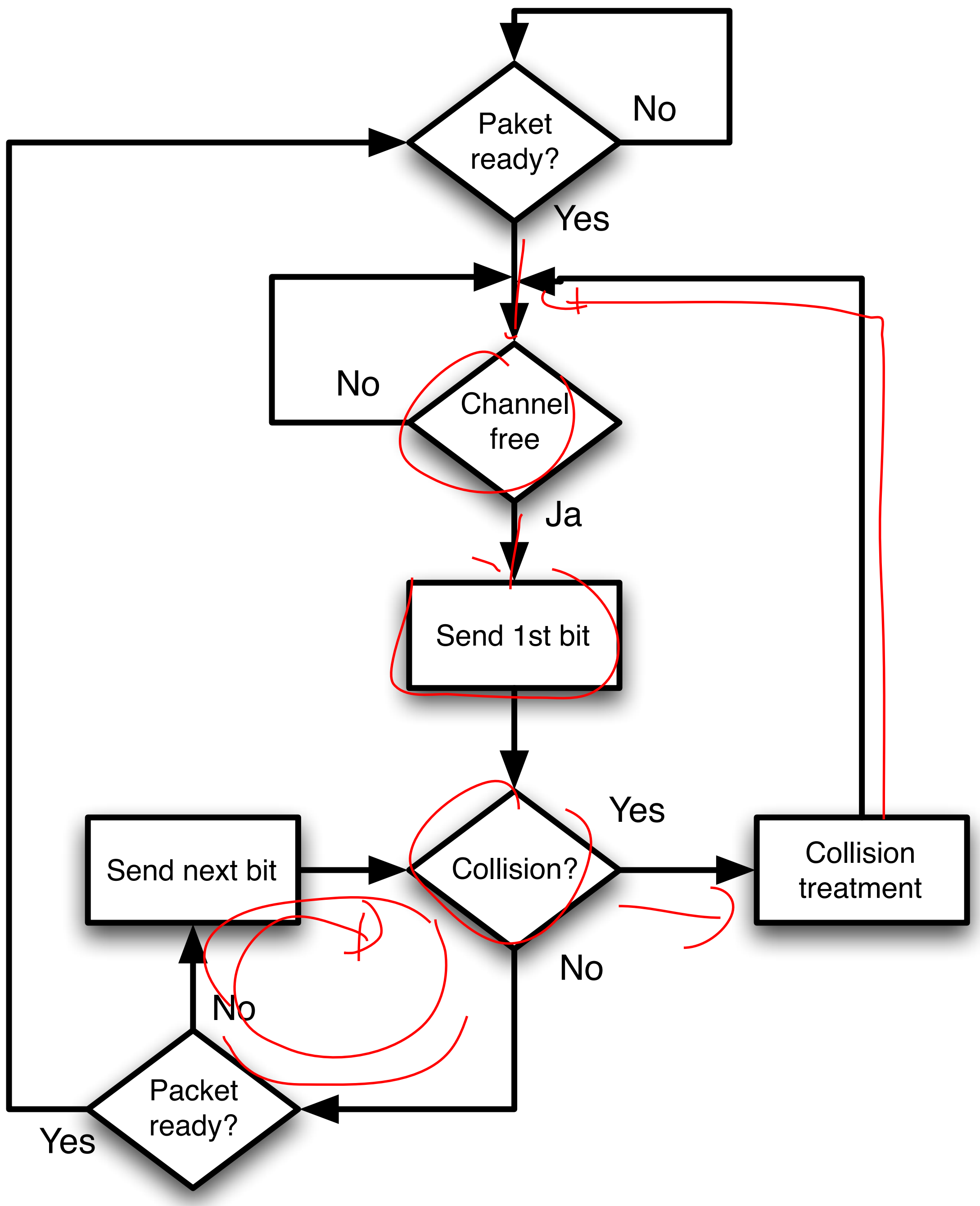


Collision Detection in Ethernet – CSMA/CD

- **CSMA/CD – Carrier Sense Multiple Access/Collision Detection**
  - Ethernet
- **If collision detection during reception is possible**
  - Both senders interrupt sending
  - Waste of time is reduced
- **Collision Detection**
  - simultaneously listening and sending must be possible
  - Is that what happens on the channel that's identical to the message?



Ethernet CSMA/CD



Computation of the Backoff

- **Algorithm: Binary Exponential Backoff**
  - k:=2
  - While a collision has occurred
    - choose t randomly uniformly from {0,...,k-1}
    - wait t time units
    - send message (terminate in case of collision)
    - k:= 2 k
- **Algorithm**
  - waiting time adapts to the number of stations
  - uniform utilization of the channel
  - fair in the long term

{0, 1}

{0, 1, 2, 3}

{0, 1, 2, 3, 4, 5 .. 7}

100

50

50

25

25

12,5

⋮

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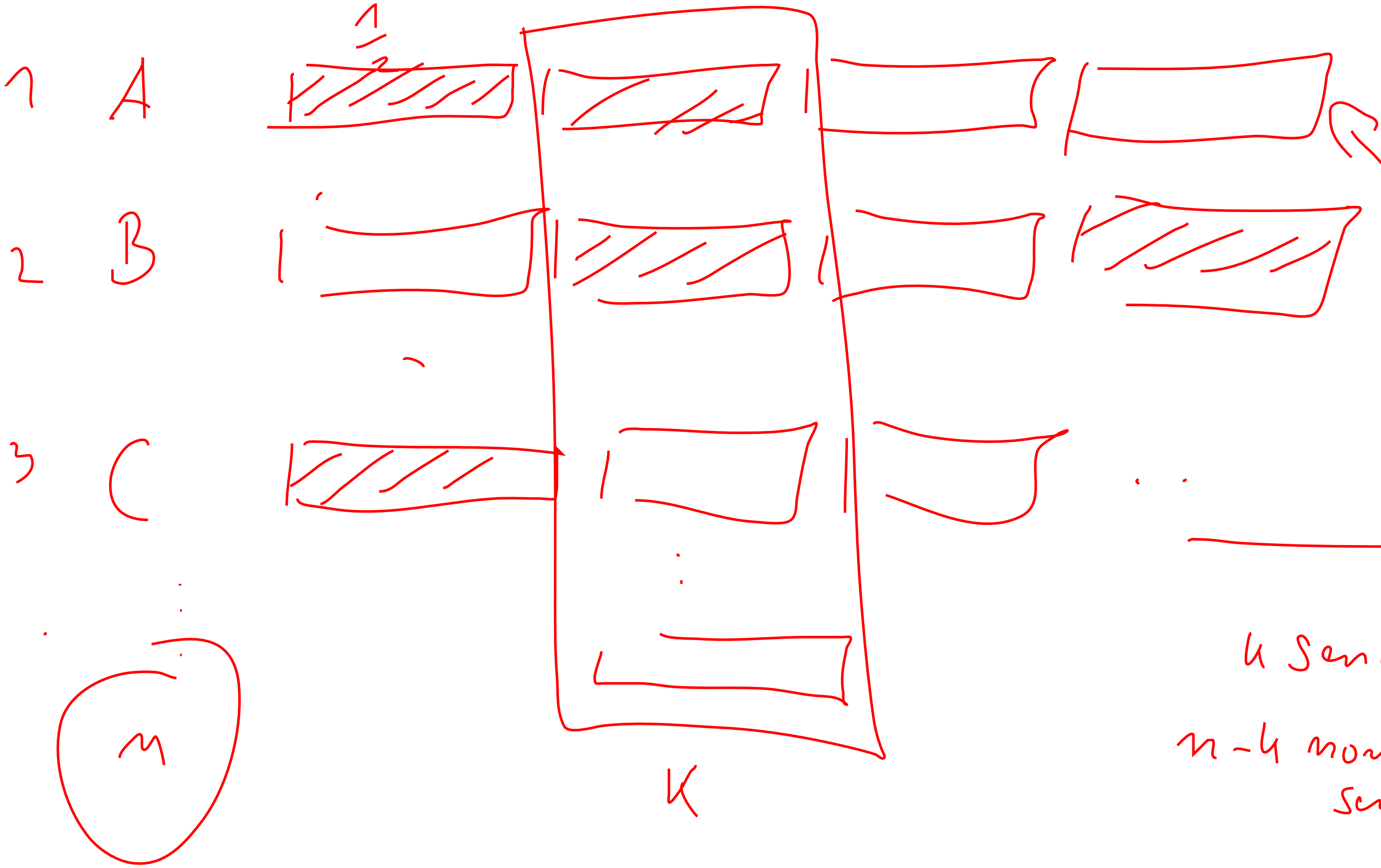


Prob. p

$$p = \frac{1}{2}$$

k senders : p^k

n−k non-senders : $(1-p)^{n-k}$

binomial coeff

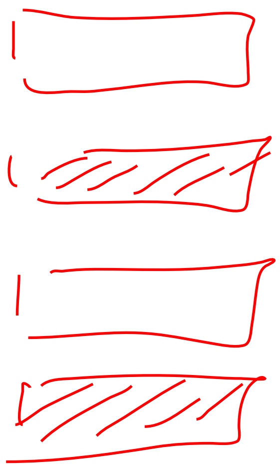
Prob of k messages $= p^k \cdot (1-p)^{n-k} \cdot \binom{n}{k}$

k out of n $\left| \; \frac{n \cdot (n-1)(n-2) \cdots (n-k+1)}{k(k-1)(k-2)\cdots 1} = \frac{n!}{k!(n-k)!} = \binom{n}{k} \right.$

1

$\vdots$

$n \to \infty$



X_n : random variabl.

$$P[X=k] = \frac{p^k \cdot (1-p)^{n-k} \binom{n}{k}}{}$$

$$E[X] = \sum_{k=1}^{n} P[X=k]\, k$$

fix : exp. number of messages

$$E[X_1 + X_2] = E(X_1) + E[X_2]$$

k:	1	2	3	4	5	6
$P[X=k]$:	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$

$$E[X_n] = n \cdot E[X_1] = p \cdot n$$

$$= n \left(\cancel{P[X_1=0] \cdot 0} + P[X_1=1] \cdot 1 \right)$$

$$= n\, p^1 \cdot (1-p)^{1-1} \cdot \binom{1}{1} = n \cdot p$$

Fix expectation, but $n \to \infty$

$$\lambda = E[X] = n \cdot p \qquad p = \frac{\lambda}{n}$$

Poisson $\quad P[X_n = k) = p^k \cdot (1-p)^{n-k} \cdot \binom{n}{k}$

$$= \left(\frac{\lambda}{n}\right)^k \cdot \left(1 - \frac{\lambda}{n}\right)^{n-k} \cdot \frac{n \cdot (n-1) \cdot \ldots \cdot (n-k+1)}{k!}$$

$n \to \infty$

$$= \frac{\lambda^k}{k!} \boxed{\left(1 - \frac{\lambda}{n}\right)^{\frac{n}{\lambda}}}^{\frac{\lambda}{n} \cdot (n-k)} \quad \frac{n(n-1) \ldots (n-k+1)}{n \cdot n \cdot n \ldots n}$$

$$= \frac{\lambda^k}{k!} \boxed{\left(\frac{1}{e}\right)^{\lambda - \frac{k\lambda}{n}}} \qquad \frac{k\lambda}{n} \to 0$$

$$\frac{n}{n} \cdot \frac{n-1}{n} \cdot \frac{n-2}{n} \cdot \ldots \frac{n-k+1}{n} \quad (\text{each} \to 1)$$

$$\boxed{\frac{\lambda^k}{k!} \cdot e^{-\lambda}}$$

$$\lim_{n \to \infty} \left(1 - \frac{1}{n}\right)^n = \frac{1}{e}$$